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Daily Bundesbank and Federal Reserve Interventions

Are they a Reaction to Changes in the Level and Volatility of the DM/$-Rate?

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Abstract: This paper reports on the results of an empirical investigation into the objectives of daily foreign exchange market intervention by the Deutsche Bundesbank and the Federal Reserve System in the U.S. dollar-Deutsche Mark market. Tobit analysis is implemented to estimate the intervention reaction functions consistently. It is found that an increase in the conditional variance in daily exchange rate returns derived from a GARCH model estimated in the paper, led the Bundesbank and the Federal Reserve to increase the volume of intervention, both in case of dollar-sales and purchases on account of their leaning against the wind policy.

Key Words: Foreign exchange intervention, exchange rates, GARCH models, tobit analysis.

JEL Classification System-Number: F31

1 Introduction

In this study the objectives of official intervention by central banks in the U.S. dollar-Deutsche Mark market will be examined. An attempt will be made to determine empirically the short term reaction functions with regard to the U.S. dollar/DM exchange market intervention by both the Deutsche Bundesbank and the Federal Reserve System. Particular attention will be paid to the respective central banks' behavior towards anticipated exchange market volatility. Applications of the GARCH model reveal that volatility is predictable in most financial markets (for a survey, see Bollerslev et al. (1992)). Shocks in daily exchange rate returns in period *t* show a considerable persistence onto the conditional volatility in consecutive periods. The conditional variance of daily returns in the U.S. dollar-Deutsche Mark exchange market will be used as a proxy for the ex ante exchange rate risk. It is expected that the central banks try

[1] We are grateful to the Deutsche Bundesbank, Hauptabteilung Ausland for kindly providing, on a confidential base, the daily data on the official interventions of the Bundesbank and the Federal Reserve, the latter only to the extent that they affected the net foreign position of the Bundesbank. Also, we want to thank Theo Nijman and two anonymous referees for helpful comments on an earlier draft of this paper. Opinions and errors are our own responsibility.

to compress the perceived risk by means of direct foreign exchange market operations.

The study concentrates on intervention of both central banks in the *spot* dollar/DM exchange market. Daily observations for the official interventions are used. Focus is on 'active' intervention which takes place *inside* the dollar/DM exchange market. It is well known that foreign exchange market participants are eager to detect any information related to official foreign exchange intervention. Central bankers, in turn, know that their actions are monitored very carefully. Therefore, it seems reasonable to assume that all interventions undertaken inside the dollar/DM exchange market are intended to influence the price formation on the market. 'Passive' intervention which takes place outside the market is left out of consideration.

The data available to this study run from February 1985 through to October 1990. As relevant subsamples have been selected four periods of at least three months with prolonged intervention in one direction: September 1987-January 1988, June 1988-September 1988, December 1988-June 1989 and August 1989-October 1989. These periods are all situated after the Louvre Agreement of February 22, 1987. Therefore, the same exchange rate policy regime applies to each making them comparable in at least one respect.

The paper is organized into five remaining sections, followed by an appendix. Section 2 examines the stated objectives of exchange market intervention by central banks in the G-7 countries in general and by the Bundesbank and Federal Reserve in particular. Section 3 presents an update of the empirical results in Eijffinger and Gruijters (1991) for periods of at least three months. The volume of Bundesbank and Federal Reserve intervention is regressed on a constant and the difference between the current exchange rate of the U.S. dollar in terms of Deutsche Marks in the Frankfurt foreign exchange market and a moving average of the exchange rate in previous days. Section 4 discusses the relevance of using the information contained in the evolution of the conditional variance of daily returns in the U.S. dollar-Deutsche Mark exchange market as an additional regressor in the short term reaction function for daily interventions. Furthermore, OLS estimation results for the amended Bundesbank and Federal Reserve intervention reaction functions are presented. Section 5 centers on the actual inappropriateness of the simple OLS estimation technique used in section 4. Tobit analysis is implemented to deal with the problem of a large proportion of zero-observations for the dependent variable in the reaction functions. Section 6 contains a summary and concluding remarks. The appendix provides some details on Tobit analysis.

2 Objectives of Exchange Market Interventions by Central Banks

In the short term all central banks have a common objective of "countering disorderly exchange market conditions". It is part of their commitment to promote a stable exchange rate system in accordance with Article IV of the Articles of Agreement of the International Monetary Fund as amended in 1978. As stated by the Working Group on Exchange Market Intervention (1983) and repeated by Dudler (1988), "disorderly market conditions" are indicated by a substantial widening of bid-asked spreads, large intraday exchange rate movements, "thin" or highly uncertain trading, destabilising impacts of essentially non-economic shocks and self-sustaining exchange rate movements which may gain a momentum of their own. The medium term objectives regard to resisting large short term exchange rate movements or "erratic fluctuations" which exceed a certain size, buying time by the central banks to reassess their policies and "leaning against the wind" which has been pursued by some over short periods and by others over longer periods. The long term objectives vary from resisting exchange rate movements which are believed to be unjustified with respect to the fundamentals (inflation, money growth, balance of payments accounts, etc.) and attempts to give some leeway to monetary policy by lessening the impact of foreign shocks on domestic monetary conditions, to resisting depreciation because of its inflationary effects and resisting appreciation in order to maintain competitiveness. Other objectives are e.g. attempts to acquire foreign currencies without generating (renewed) downward pressure on the domestic currency.

According to the Working Group on Exchange Market Intervention (1983) the Bundesbank "(...) has sought from the onset of floating to counter disorderly market conditions, dampen 'erratic' short-term exchange rate fluctuations and smooth out excessive swings in the DM/U.S. dollar rate over longer periods" (p. 13) whereas Smith and Madigan (1988) state that "for the period since March 1973 as a whole (...) it is probably correct to say that the United States had no exchange rate objective" (p. 188). Obviously, for the large U.S. economy exchange rate movements are relatively unimportant in their ultimate repercussions on domestic growth and inflation. Therefore, as its maximum tolerable exchange rate changes are smaller, the Bundesbank will feel the need to intervene earlier than the Fed for given movements of the U.S. dollar/DM-rate. On the other hand, the weight assigned to exchange rate stabilization might be larger for the Federal Reserve after the Louvre Accord. While coordinated interventions are expected to have a larger chance of affecting the development of the exchange rate through their larger announcement effect, the Bundesbank will urge the Fed to do its bit, or the other way around.

Previous empirical studies to intervention reaction functions of central banks refer to the longer term objectives of exchange market intervention and have used monthly or quarterly intervention data (for a survey, see Almekinders and Eijffinger, 1991). These studies usually ignore or deduct from the short term strategy of "countering disorderly market conditions" which results in the smoothing of exchange rate volatility from day to day and even during the day.

Our empirical study deliberately focuses on the shorter term objectives of intervention in the dollar-DM exchange market. Daily intervention data of the Bundesbank and the Federal Reserve are used. The disadvantage of such an approach is the vanishing relation between intervention and the "fundamentals" which are measured on monthly or quarterly base. Nevertheless, this approach has a decisive advantage, because it captures better the frequency and pattern of exchange market intervention with respect to "countering disorderly market conditions" and "leaning against the wind" over shorter periods. Thereby, it should be noticed that the intervention behavior of central banks is not only reflected in the direction and volume, but also in the timing and technique of intervention. The timing refers to the question whether the exchange market is "thin" and uncertain or not, while the technique relates to the way in which a central bank implements its intervention, *i.e.* by domestic and possibly foreign commercial banks or by currency brokers with different announcement effects.

Despite the importance of both timing[2] and technique for intervention behavior, these elements can not be taken into account by our study and will surely detract from the explanatory power of the intervention reaction functions.

The majority of the previous studies formulate the reaction function rather ad hoc. In some studies, however, it is derived formally by combining a policy loss function for the central bank with a set of equations describing the determination of the exchange rate (S_t). In the latter case much depends on the initial formulation of the loss function (L_t) which is to be minimized with respect to the constraints implied by the exchange rate model to arrive at the actual intervention reaction function. A common assumption is that the central bank wishes to limit deviations from a target level for the exchange rate (S_t^T):

$$L_t = (S_t - S_t^T)^2 \tag{1}$$

To capture intervention carried out on account of a "leaning against the wind" policy, the target level for the exchange rate can be thought of as representing past levels of the exchange rate. This follows immediately from the definition of smoothing exchange rate fluctuations: whether or not the exchange rate was considered to be at a desirable level in the previous period(s), deviations from the target level will be countered.

Neumann (1984) implements a flow market model for the determination of the exchange rate. He derives an intervention reaction function according to which the central bank of the home country supplies amounts of home currency to the market when the exchange rate of the foreign currency in terms of the home currency is lower than the target rate ($S_t < S_t^T$) and when an increase in the expected risk premium on assets denominated in the home currency raises speculative demand for that currency. It should be noticed that the serious measurement problems surrounding "risk premiums" are well established.

[2] Goodhart and Hesse (1993) reveal some interesting aspects of the timing of foreign exchange intervention.

3 An Empirical Study of the Reaction Functions of the Deutsche Bundesbank and the Federal Reserve System

An empirical study of the reaction function for daily interventions by the Deutsche Bundesbank and the Federal Reserve System in the spot U.S. dollar-deutsche mark exchange market must take account of the development of the dollar-DM exchange rate between successive days (interday), as well as in the course of these days (intraday)[3]. In this study the intraday development is approximated by three observations per day:

1. the opening rate (primo) at 8.30 hours;
2. the fixing rate (official middle rate) at 13.00 hours;
3. the closing rate (ultimo) at 16:30 hours (Frankfurt time).

Because the opening and closing rates are only available since February 1985[4], as sample is chosen the period from February 1985 until October 1990. Furthermore, the study makes use of daily observations for the official interventions in the dollar-DM exchange market, which can be divided in two parts:[5]

a. U.S. dollar-interventions of the Deutsche Bundesbank expressed in deutsche marks against the DM/dollar intervention rate of that day;
b. DM-interventions of the Federal Reserve Bank of New York, acting on behalf of the Federal Reserve System, so far as these operations affect the net foreign position of the Bundesbank. This happens e.g. when the Federal Reserve finances its DM-sales by calling on the swap agreement with the Bundesbank or from its DM-balances at the Bundesbank, or when the Federal Reserve invests its DM-purchases at the Bundesbank.

The sample period (February 1985-October 1990) consists of 1439 trading days. On the majority of these days no interventions were carried out by the Bundesbank and the Federal Reserve System. Months which comprise less than four interventions are left out of consideration. As relevant subsamples have

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[3] Goodhart and Hesse (1993) assess central bank foreign exchange market intervention virtually in continuous time. However, their investigations are based on *reported* intervention observations which appeared on Reuters screen information. This gives a far from exact representation of actual intervention operations. Moreover, reported intervention observations do not contain information on the *actual* amount of intervention.

[4] Data for the opening, fixing and closing DM-dollar rate are taken from: Statistische Beihefte zu den Monatsberichten der Deutschen Bundesbank, Reihe 5: Die Währungen der Welt, Februar 1985-November 1990, Tabelle 6: Kassa-Kurse des US dollar in Tagesverlauf.

[5] Data on the official interventions of the Bundesbank and Federal Reserve, to the extent that they affected the net foreign position of the Bundesbank, were kindly provided by the Deutsche Bundesbank, Hauptabteilung Ausland on a confidential base. Therefore, this study comprises no exact data, nor any figures of these interventions.

been selected four periods of at least three months with prolonged interventions in one direction by either of the central banks. The reason for this will be explained in the next section.

The first period runs from September 1987 (for the Fed: October 1987) to January 1988. It seems that during this period, the G-3 countries were no longer willing to direct monetary policy at stabilizing exchange rates as was agreed upon at the Louvre meeting. Furthermore, the October 1987 stock market crash is likely to have caught exchange market participants off balance, calling for dollar supporting intervention.

In the first half of 1988, the U.S. dollar recovered gradually from its steep decline in the aftermath of the stock market crash. The dollar's upward movement against the mark strengthened vigorously during the second period considered in this paper, June 1988 through September 1988. It appeared to be possible for the U.S. economy to experience a relatively strong growth without frustrating external adjustment. The announcement of U.S. trade deficits which were much smaller than expected made exchange market participants to anticipate a further appreciation of the dollar.[6] Coordinated central bank interventions in August 1988 to counteract this rise was supported by the Bundesbank's move, on August 25, to raise its discount rate by $\frac{1}{2}$ percentage point leading to a narrowing of the interest differential in favor of the dollar.

The third period runs from December 1988 to March 1989 for the Bundesbank. For the Federal Reserve System it begins in January 1989 and ends in June 1989. Political strains in Germany and Japan on the one hand, and a widening short-term interest differential favoring the U.S. dollar over the deutsche mark on the other hand put the value of the dollar under upward pressure. Thereby, the market temporarily overlooked the structural weakness of the U.S. dollar caused by the persistent U.S. 'twin deficit'. The buoyancy of the dollar and thus the perceived need for (U.S.) intervention finally subsided in late June 1989. Indications of a deceleration of economic growth and a lessening of inflationary pressure led to market expectations of an easier U.S. monetary policy stance and lower short-term interest rates.

As fourth period is chosen August 1989-October 1989. During this period, again, the dollar came under upward pressure. The currency was strengthened by lower than expected U.S. trade deficits for June and July released on August 17 and September 15, respectively, and favorable employment and retail sales data lowering the probability, as perceived by market participants, of an easing of U.S. monetary policy. By means of official sales of dollars, in part undertaken after a G-7 meeting on September 23, the Bundesbank and the Fed tried to convince market participants that the G-7 monetary authorities were firmly committed to resisting the dollar's rise and maintaining exchange rate stability.

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6 Empirical evidence on the relation between trade balance announcements and exchange rate movements is presented in, *e.g.*, Hogan et al. (1991), Klein et al. (1991) and Eijffinger and Gruijters (1992).

Quirk (1977), when using monthly data, distinguishes intervention on account of a "leaning against the wind" policy, given by

$$INV_t = a(S_t - S_{t-1}) \tag{2}$$

from intervention consistent with gliding parities calculated as a moving average of previous levels of the exchange rate which is of the form

$$INV_t = b\left(S_t - \sum_i a_i S_{t-i}\right), \quad \text{with } \sum_i a_i = 1 \tag{3}$$

where INV_t is the volume of intervention expressed in the home currency and S_t is the spot exchange rate (home currency price of foreign currency). The same two specifications can be distinguished when daily data are used; the latter specification is central to the investigations in Eijffinger and Gruijters (1991) of which an update will be presented in this section.[7]

The interventions by the Deutsche Bundesbank (INV_t^{DBB}) and the Federal Reserve System (INV_t^{FED}) in the U.S. dollar-deutsche mark exchange market are explained by a constant and the difference between the opening rate of the dollar in DM (S_t^P) and the seven-days moving average of the opening rate, fixing rate (S_t^F) and closing rate (S_t^U) of the dollar:

$$INV_t^{DBB/FED} = a_0 + a_1\left(S_t^P - 1/21 \sum_{n=1}^{7} S_{t-n}^{P/F/U}\right) + \mu_t \tag{4}$$

where μ_t is the residual of the reaction function. The exchange market interventions by the Bundesbank and Federal Reserve are both expressed in billions of Deutsche Marks. The interventions are positive if the central bank buys U.S. dollars in return for Deutsche Marks. The Deutsche Mark/U.S. dollar-exchange rate is defined as the spot value of one U.S. dollar expressed in Deutsche Marks at the Frankfurt exchange. The constant (a_0) reflects, when significant, a bias of the intervening central bank with respect to the DM/$-rate based on the development of the "fundamentals", such as the (long) capital account, the current account, the inflation rate and the growth rate of the money stock in Germany and the United States. A positive constant represents an autonomous bias of the central bank concerned towards a dollar appreciation *vis-à-vis* the deutsche mark in the medium (and long) run[8]. The smoothing or "leaning against the wind" coefficient (a_1) reflects the reaction of the central bank by exchange market intervention on a deviation of the current exchange rate – i.e. the opening rate of the day in the Frankfurt market – from the average level of the exchange rate during the previous days. As a proxy for the average level of

[7] Eijffinger and Gruijters (1991) compare a three-days, five-days and seven-days moving average, respectively. This study, however, concentrates on a seven-days moving average only, because this generally turned out to give the best empirical results.

[8] The constant is a consequence of the monthly or quarterly base of the data on "fundamentals" (inflation, money growth, balance of payments accounts, etc.). These data would lead to rather sticky regressors for the "fundamentals" in a daily model of exchange market intervention.

the exchange rate is chosen a moving average of the opening, fixing and closing rates during the previous seven trading days in the Frankfurt market. During periods of an increasing (decreasing) value of the U.S. dollar in terms of DM, the difference between the opening rate of the day and the moving average (the bracketed term in equation (4)) tends to be positive (negative). Consequently, a positive (negative) value of the coefficient a_1 implies that the central bank tends to buy (sell) U.S. dollars when the exchange rate of one U.S. dollar in terms of Deutsche Marks is rising (declining). While the Bundesbank and the Federal Reserve are supposed to pursue a policy of "leaning *against* the wind", the smoothing coefficient is expected to have a negative sign. This means that the central banks try to dampen the volatility of the DM-dollar rate in the short-run by exchange market intervention.[9]

The results from estimating equation (4) by ordinary least squares (OLS) are reported in Table 1. The constant (a_0) is significant in all eight regressions. For the first subsample it has a positive sign consistent with the fact that both central banks only bought U.S. dollars during that period. The opposite case applies to the other three subsamples. The smoothing or "leaning against the wind" coefficient (a_1) has the expected negative sign except for the fourth subsample. In the case of the Bundesbank, this "leaning *with* the wind" is statistically significant. Neither a closer inspection of the data nor a broad characterisation of the major economic issues during the particular period reveal an explanation for this apparent "leaning *with* the wind" by both the Bundesbank and the Fed. The announcement of a smaller than expected U.S. trade deficit in August and September 1989 pushed the (value of the) dollar above DM 2.00 inducing dollar sales by the central banks.

The values of the Durbin-Watson test statistic given in Table 1 clearly indicate that first-order autocorrelation in the residuals of (4) is a problem. Although the lower bound of the critical value for each regression varies with the number of observations in the subsample, it can easily be checked that only for the fourth subsample in the case of the Federal Reserve the null hypothesis of uncorrelated errors is not rejected. In the following sections a different specification of the reaction function and a more appropriate estimation technique will be used to describe the intervention behavior more satisfactory.

4 The Reaction Towards Anticipated Exchange Rate Volatility

In the previous section the reaction of the central banks to a divergence of the actual from the desired exchange rate was estimated. The desired level of the

[9] However, if the smoothing or "leaning against the wind"coefficient unexpectedly has a positive sign, then the central bank concerned actually reacts by a policy of "leaning *with* the wind"and thus amplifies the exchange rate volatility in the short-run. Such a policy is expected to be an exception.

Table 1. OLS estimation results for the reaction function in (4)

$$INV_t^{DBB/FED} = a_0 + a_1\left(S_t^P - 1/21 \sum_{n=1}^{7} S_{t-n}^{P/F/U}\right)$$

period	a_0	a_1	$\bar{R}^2$	DW	Obs.
Deutsche Bundesbank					
9:87–1:88	0.035	−2.957	0.241	1.41	105
	(3.18)	(−5.83)			
6:88–9:88	−0.138	−4.490	0.086	1.59	86
	(−4.87)	(−3.00)			
12:88–3:89	−0.029	−2.695	0.152	1.59	84
	(−2.64)	(−3.98)			
8:89–10:89	−0.027	0.939	0.068	1.33	66
	(−2.77)	(2.40)			
Federal Reserve System					
10:87–1:88	0.036	−2.044	0.117	1.35	83
	(2.54)	(−3.45)			
6:88–9:88	−0.080	−4.444	0.137	1.23	86
	(−3.63)	(−3.80)			
1:89–6:89	−0.102	−4.344	0.150	1.67	124
	(−5.25)	(−4.76)			
8:89–10:89	−0.075	0.226	−0.013	1.86	66
	(−4.71)	(0.38)			

Notes:
t-statistics in parentheses.
$\bar{R}^2$ is the squared multiple correlation coefficient adjusted for degrees of freedom
DW is the Durbin-Watson statistic for first-order autocorrelation.
Obs. gives the number of observations for each period.

exchange rate was proxied by the seven-days moving average of the exchange rate. Therefore, the central banks' reaction patterns were assumed to be guided by realized values of the exchange rate.

The evolution over time of the variance or standard deviation of exchange rate changes and other statistical properties derived from the behavior of exchange rates have recently become an intensively studied subject. Several recent studies have applied Engle's [1982] autoregressive conditionally heteroskedastic (ARCH) model and Bollerslev's [1986] extension to a generalized ARCH (GARCH) model to describe time-varying variances in exchange rates. The purport of the meanwhile extensive GARCH literature is that volatility in daily returns is predictable in most financial markets. In several applications it has been shown that there is a long term persistence in the effects of shocks in period t onto the conditional variance of exchange rates in period $t + s$ for large s. On the assumption that central banks are aware of this regularity, the forward looking nature of foreign exchange market operations can be tested by including a conditional variance term in the reaction function.

The investigations in this paper are concerned with exchange rate risk associated with *interday* movements of the exchange rate only. Exchange rate risk associated with *intraday* exchange rate developments in our opinion applies when studying noise-trading and the interaction between central banks and exchange market participants which behave as 'chartists' (see *e.g.* Allen and Taylor (1990) and Hung (1991) for a more extensive treatment of this subject).[10] An empirical investigation of this interaction would require the use of intradaily data of interventions, exchange rates and even trading volumes.

The conditional variance of daily returns in the U.S. dollar-deutsche mark exchange market will be used as a proxy for the anticipated exchange rate volatility. An increase in the conditional variance is not only likely to cause "disorderly market conditions" on the foreign exchange market. It may have an adverse effect on the volume of international trade as well. Until recently, the effect of exchange rate volatility on the volume of international trade remained an unresolved issue. Theory is indeterminate on this issue.[11] Furthermore, in a recent article Bini Smaghi (1991) explains why it is so difficult to find any empirical relationship. Using sufficiently disaggregated data on trade flows, he finds that, for the period 1976–1984, the standard deviation of weekly rates of change of the intra-EMS effective exchange rate during a quarter had a significantly negative effect on the volume of exports of the countries considered (Germany, France and Italy) in the same quarter.

From the sample as a whole four periods of at least three months with prolonged interventions in one direction by one of the central banks have been selected. This is done because the variance of a time series is positive by definition and because it seems reasonable to expect a central bank, ceteris paribus, either to buy *or* sell more U.S. dollars in case of an increase in the conditional variance of the return series depending on the initial direction of intervention. Therefore, the expected sign of the coefficient for the conditional variance term in the intervention reaction function is positive (negative) when the period is characterised by purchases (sales) of U.S. dollars by the central banks.

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[10] The following statement made by Gleske (1982, p. 265) relates to this interaction: "Under certain circumstances, only small interventions may suffice to curb or even reverse an unwanted movement in the exchange rate. In other cases even large interventions may result in the opposite effect; when market participants are convinced of the strength of a fundamental trend..." (our translation).

[11] An increase in exchange rate volatility does not necessarily have to lead to a decline in the volume of trade. An income and a substitution effect are at work. The substitution effect of resources shifted away from the traded-goods sector when volatility increases may be dominated by an income effect working in the opposite direction. De Grauwe (1988) shows that this is the case if producers are sufficiently risk averse and increase resources in the export sector to offset the drop in expected utility of export revenue caused by the rise in exchange rate volatility.

The periods selected are all situated after the establishment of the Louvre Agreement of February 22, 1987. Estimation results in Almekinders (1992) point to a marked change in the stochastic process generating the DM-U.S. dollar return series as of that date. Furthermore, it appeared that the process remained relatively stable at least until October 1989. Therefore, the sample period used to estimate the GARCH model runs from February 23, 1987 through to October 31, 1989 totalling 677 observations. The model looks as follows:

$$
\begin{aligned}
&100(\log S_t^U - \log S_{t-1}^U) = b_0 + \varepsilon_t \\
&\varepsilon_t | \Omega_{t-1} \sim N(0, h_t) \qquad (5) \\
&h_t = \pi + \alpha\varepsilon_{t-1}^2 + \beta h_{t-1}
\end{aligned}
$$

with π, α, $\beta > 0$, $\alpha + \beta < 1$. The first line represents the mean equation of the model, expressed in closing rates, (S^U), ε_t is the residual of the mean equation and the second line states that it has a conditional normal distribution with mean zero and variance h_t. Ω_{t-1} indicates the information available to exchange market participants as of time $t-1$. The third line of the model defines the variance equation (h_t). The maximum likelihood estimation results are shown in Table 2. The constant in the mean equation (b_0) does not differ significantly from zero. Obviously, the DM/dollar-rate did not increase uniformly across the sample. The high standard deviation of the daily returns in the dollar-DM market renders an insignificant constant in the mean equation. The other coefficients of the GARCH model in (5) are highly significant. The value of the likelihood ratio (LR) test statistic in the last column of Table 2 indicates that the null hypothesis H_0: $\alpha = \beta = 0$ can be soundly rejected. This implies that the random walk model with a GARCH error term fits the data better than the random walk model with a Gaussian error term. Although the residuals still exhibit some excess kurtosis, it can be argued that the conditional normal specification in (5) captures the stylized facts of the DM/dollar-exchange rate fairly well. The estimation results depicted in Table 2 are used to generate a series for

Table 2. Maximum likelihood estimates for the parameters of the GARCH model (see equation (5))

b_0	π	α	β	$\log L$	$Q(12)$	$Q^2(12)$	m_3	m_4	$LR(2)$
0.015	0.021	0.073	0.874	−649.34	10.29	20.63	0.04	4.29	35.68
(0.65)	(2.77)	(4.47)	(31.51)						

Notes:
t-statistics in parentheses.
m_3 and m_4 give the sample skewness and kurtosis for the residuals respectively.
$Q(12)$ and $Q^2(12)$ refer to the Ljung-Box portmanteau test for up to 12'th order serial correlation in the levels and the squares of the residuals respectively. The critical value for a 5%-level test is 21.0.
$LR(2)$ gives the value of the test statistic for the likelihood ratio test under the nullhypothesis that the variance is conditional homoskedastic H_0: $\alpha = 0$, $\beta = 0$. As the alternative hypothesis is H_1: $\alpha \geq 0$, $\beta \geq 0$, the LR-statistic does not have a χ^2-distribution with two degrees of freedom. The tabulated critical value for a 5%-level test is 5.135 (Kodde and Palm (1986)).

the conditional variance of the daily DM/dollar-return. The unconditional or average variance of the return series[12] for the sample considered in Table 2, σ^2, is used as a starting value:

$$\sigma^2 = \pi/(1 - \alpha - \beta) = 0.396$$

The path of the conditional variance (h_t) for the period from September 1987 to July 1988 can be seen in Figure 1. An upturn of the conditional variance during the first period of prolonged (dollar-supporting) intervention stands out. A major strengthening of the U.S. dollar *vis-à-vis* the DM marks the beginning of the second subsample.

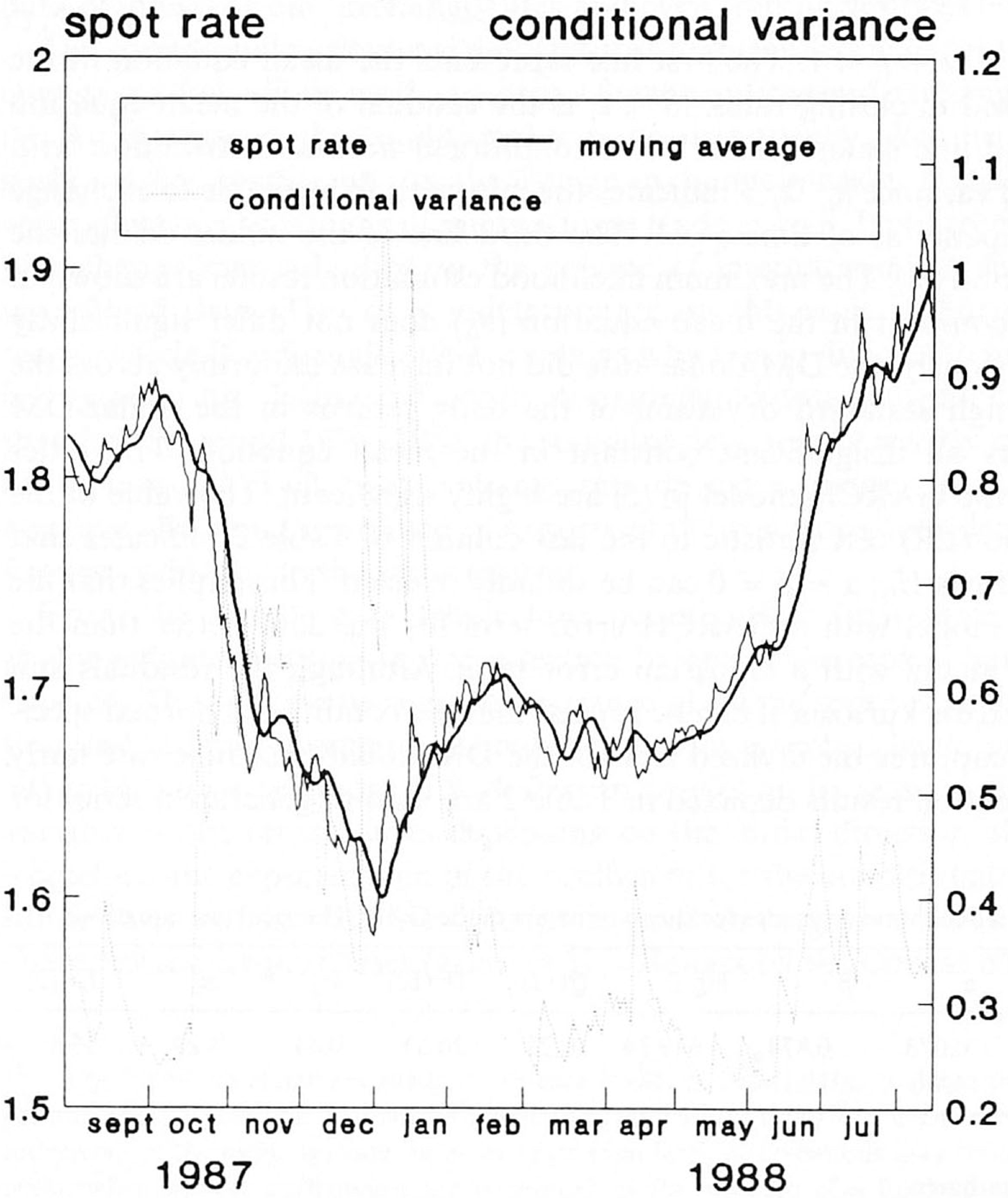

Fig. 1. DM/$-rate and conditional variance

[12] The variance equation in (5) can be written as

$$h_t = \sigma^2 + \alpha \sum_{i=0}^{\infty} \beta^i(\varepsilon_{t-i-1}^2 - \sigma^2)\,, \qquad \text{with } \sigma^2 = \pi/(1 - \alpha - \beta)\,.$$

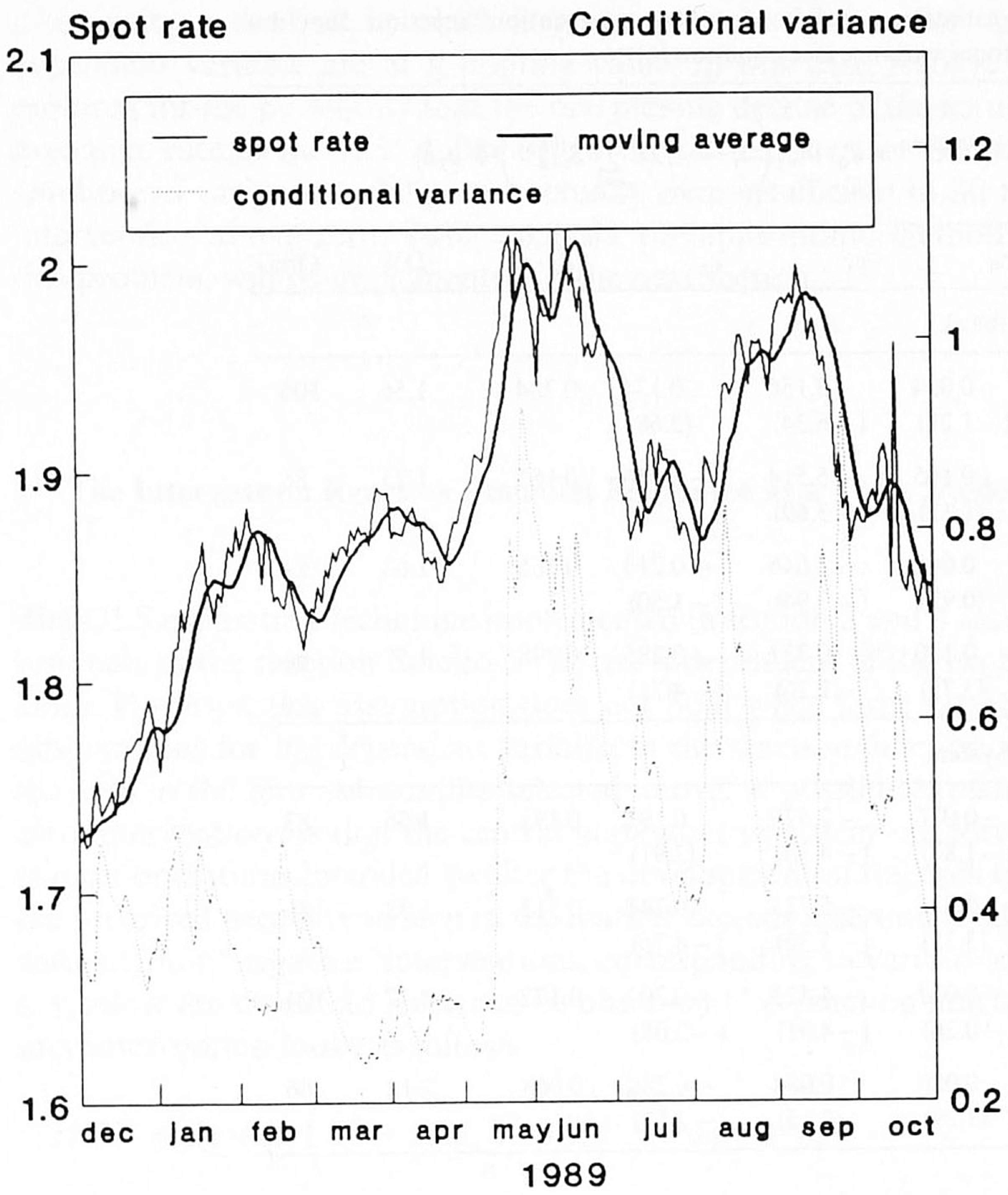

Fig. 2. DM/$-rate and conditional variance

The intervention reaction function for the Deutsche Bundesbank and the Federal Reserve System including the conditional variance of the daily return in the U.S. dollar-deutsche mark market as an additional explanatory variable, looks as follows:

$$INV_t^{DBB/FED} = c_0 + c_1\left(S_t^P - 1/21 \sum_{n=1}^{7} S_{t-n}^{P/F/U}\right) + c_2 h_t + \mu_t \tag{6}$$

OLS estimation results for equation (6) are reported in Table 3. When comparing these results with those in Table 1, is it obvious that the conditional variance coefficient (c_2) draws explanatory power away from the constant (c_0) while the smoothing or "leaning against the wind" coefficient (c_1) remains of equal magnitude approximately. Furthermore, the overall explanatory power of the reaction function, as measured by the squared multiple correlation coefficient adjusted for degrees of freedom, is higher and the problem of first-order autocorrelation

Table 3. OLS estimation results for the intervention reaction function including conditional variance (see equation (6))

$$INV_t^{DBB/FED} = c_0 + c_1\left(S_t^P - 1/21 \sum_{n=1}^{7} S_{t-n}^{P/F/U}\right) + c_2 h_t$$

OLS	c_0	c_1	c_2	$\bar{R}^2$	DW	Obs.
Deutsche Bundesbank						
9:87–1:88	−0.034	−3.156	0.134	0.284	1.56	105
	(−1.21)	(−6.34)	(2.68)			
6:88–9:88	0.105	−5.514	−0.588	0.151	1.75	86
	(1.13)	(−3.69)	(−2.72)			
12:88–3:89	0.047	−2.646	−0.213	0.165	1.63	84
	(0.92)	(−3.94)	(−1.50)			
8:89–10:89	0.130	0.723	−0.285	0.298	1.57	66
	(3.75)	(2.26)	(−4.71)			
Federal Reserve System						
10:87–1:88	−0.076	−2.573	0.192	0.192	1.56	83
	(−1.87)	(−4.32)	(2.91)			
6:88–9:88	0.226	−5.733	−0.740	0.313	1.38	86
	(3.35)	(−5.32)	(−4.75)			
1:89–6:89	−0.012	−4.423	−0.207	0.172	1.77	124
	(−0.26)	(−4.91)	(−2.08)			
8:89–10:89	0.080	0.084	−0.280	0.068	2.12	66
	(1.29)	(0.15)	(−2.57)			

notes:
see Table 1

in the residuals seems to have become less severe. Most importantly, the conditional variance coefficient has the expected sign in all cases. It is positive in the first subsample when both central banks only bought U.S. dollars and negative in the three remaining subsamples with the central banks selling U.S. dollars.

A straightforward interpretation of the estimated coefficients in the Bundesbank reaction function for the sample period September 1987-January 1988 could be the following. A one pfennig decline of the actual level of the exchange rate of the U.S. dollar below the desired level led the Bundesbank to buy DM 31.56 million worth of U.S. dollars on average. Furthermore, an increase in the conditional variance by 10 points, say from 0.30 to 0.40, caused by a larger than average percentage change in the DM/\$-exchange rate during the previous day, ceteris paribus induced the Bundesbank to buy an additional DM 13.4 million worth of U.S. dollars. However, the simple OLS estimation technique does in fact not yield consistent estimates for the coefficients in the reaction functions when using a data set in which large proportions of the observations for the dependent variable are at a limiting value, in this case zero. A correction is required for the possibility that the one pfennig decline of the actual level of the exchange rate of the U.S. dollar below the desired level or the increase in the conditional variance by 10 points actually were insufficient to lift the volume of intervention above zero. Tobit analysis, the appropriate method to deal with this problem, will be implemented in the next section.

5 The Intervention Reaction Function Estimated as a Tobit Model

The OLS estimation technique implemented in section 3 and 4 assumes that the residuals of the reaction functions (μ_t) are independent of the explanatory variables. However, this assumption does not hold when large proportions of the observations for the dependent variable in the reaction function are zero, as is the case in the four subsamples selected above. A possible explanation for the zero interventions is that the central bank does not carry out foreign exchange market operations intended to alter the development of the exchange rate until the perceived necessity to step in the market exceeds a certain level. Neither this necessity nor "negative" interventions, corresponding to various levels of necessity below the threshold level, can be observed.[13] A reaction function for necessary intervention looks as follows

$$INV_t^* = d_0 + d_1\left(S_t^P - 1/21 \sum_{n=1}^{7} S_{t-n}^{P/F/U}\right) + d_2 h_t + \mu_t^* \tag{7}$$

where INV_t^* is the necessary amount of intervention and the residual μ_t^* is assumed to be an identically and independently distributed random variable with mean zero and variance σ^2. The relationship between observed and necessary intervention applying to both buying and selling of foreign exchange is

$$\begin{aligned} INV_t &= INV_t^* && \text{if } INV_t^* > 0 \\ &= 0 && \text{if } INV_t^* \leq 0 \end{aligned} \tag{8}$$

The coefficients in Table 3 are biased estimators of d_0, d_1 and d_2 in equation (7). Therefore, μ_t is not identically distributed with mean zero and variance σ^2.

In Tobit analysis, named after Tobin (1958) who pioneered this type of analysis, the parameters in (7) are estimated consistently applying maximum likelihood procedures (for more details on Tobit analysis, see the Appendix).

[13] Periods of prolonged interventions in one direction were selected to rule out the possibility that "negative" interventions are simply observed opposite interventions (*i.e.* selling instead of buying and *vice versa*).

Table 4 reports the Tobit regression results for equation (7). In a qualitative sense these do not differ very much from the OLS results reported in Table 3. The puzzling "leaning *with* the wind" coefficient in the fourth subsample for the Bundesbank is no longer significant. The Tobit regression coefficients overstate the actual effect of unit changes in the explanatory variables on the volume of intervention. A correction is required for the possibility that for instance an increase in the divergence of the actual spot rate from the seven-days moving average of the exchange rate does not lead to nonzero interventions. Therefore, the coefficients in Table 4 have to be multiplied by the expected probability that the volume of intervention is larger (in the first subsample for both central

Table 4. Tobit regression results for the intervention reaction function including conditional variance (see equation (7))

$$INV_t^{DBB/FED} = d_0 + d_1\left(S_t^P - \frac{1}{21}\sum_{n=1}^{7} S_{t-n}^{P/F/U}\right) + d_2 h_t$$

period	d_0	d_1	d_2	Log L	Prob.	$LR(2)$	Obs.
Deutsche Bundesbank							
9:87–1:88	−0.448	−9.998	0.384	−216.02	0.1425	41.65	105
	(−3.79)	(−5.31)	(2.16)				
6:88–9:88	0.327	−7.074	−0.911	−429.50	0.6421	15.50	86
	(2.45)	(−3.40)	(−3.06)				
12:88–3:89	0.252	−9.140	−0.291	−223.08	0.2530	28.98	84
	(2.03)	(−4.34)	(−0.87)				
8:89–10:89	0.522	0.824	−0.704	−122.72	0.0754	15.00	66
	(3.78)	(0.86)	(−3.47)				
Federal Reserve System							
10:87–1:88	−0.877	−10.245	0.869	−148.07	0.0821	22.54	83
	(−3.41)	(−3.74)	(2.62)				
6:88–9:88	1.037	−14.971	−1.786	−214.88	0.1925	29.50	86
	(4.25)	(−4.35)	(−3.78)				
1:89–6:89	0.403	−9.510	−0.493	−381.74	0.2703	23.00	124
	(3.23)	(−4.34)	(−2.15)				
8:89–10:89	0.473	−0.255	−0.673	−184.14	0.2272	5.68	66
	(2.61)	(−0.17)	(−2.33)				

Notes:
see Table 1.
Prob. gives the expected probability of an intervention volume larger (in the first subsample for both central banks) or smaller (in the other subsamples) than zero.
$LR(2)$ gives the value of the test statistic for the likelihood ratio test that the explanatory variables, other than the constant, have no impact on the volume of intervention. The critical value for a 5%-level test for H_0: $d_1 = d_2 = 0$ is 5.99.

banks) or smaller (in the other subsamples) than zero. This probability can be derived from the Tobit regression equation with the independent variables set equal to their mean values. For each regression it is given in Table 4. These probabilities *grosso modo* correspond with the (order of the) actual proportions of intervention days in each subsample. At first sight, the expected probability in the second subsample for the Bundesbank, 0.6421, seems to be an outlier. However, the Bundesbank intervened on 57 of the 86 trading-days from June 1988 through September 1988, the calculated proportion of intervention days being $57/86 = 0.663$. In the other cases, the calculated probabilities underestimate the proportion of days with nonzero interventions.

6 Conclusions

The estimation results presented in this study indicate that both the Bundesbank and the Federal Reserve System conducted their official foreign exchange operations consistently. Daily intervention data were available. This made it possible to test whether intervention by the Bundesbank and the Fed was guided by their commitment to promote a stable exchange rate system and, thus, whether they tried to counter "disorderly market conditions" from day to day. A "leaning against the wind" policy appears to have prevailed across four post-Louvre subsamples of at least three months. In one of the subsamples, a significant "leaning *with* the wind" coefficient was found initially. However, it turned insignificant when Tobit analysis, the appropriate estimation technique given the large proportion of zero-observations for the volume of intervention, was implemented.

The "leaning against the wind" coefficient relates the volume of intervention on day t to the difference between the opening rate of the U.S. dollar in deutsche marks at the Frankfurt foreign exchange market and a seven-days moving average of the opening, fixing and closing rate. It should be noticed that the moving average refers to realized values of the exchange rate. An attempt has been made to reveal a glimpse of the forward looking nature of foreign exchange market operations by including a conditional variance term in the intervention reaction function. In fact, this study investigates whether the central banks take into account, the well established empirical regularity that daily returns on foreign exchange markets show clusters of outliers, *i.e.* that exchange rate volatility is predictable to some extent. Estimation results presented in this study confirm recent evidence that the GARCH model gives a good description of the statistical properties of daily exchange rate returns on the U.S. dollar-deutsche mark market. With the conditional variance modeled as a weighted average of the variance in past days with geometrically declining weights, the GARCH model can capture the stylized fact of clusters of large DM/dollar-returns. The time series for the conditional variance is derived from the estimated GARCH model. The estimated coefficient for the conditional variance term in the intervention reaction functions has the expected sign in all cases. It is found that an increase in the conditional variance led the central banks to increase the volume of intervention, both in case of dollar-sales and purchases on account of their "leaning against the wind" policy. In other words, both central banks take full account of exchange market uncertainty with respect to their intervention policy.

There seem to be some good reasons for this accentuation of the central banks' presence on the foreign exchange market. An increased conditional variance of daily exchange rate returns is apt to cause "disorderly conditions" on the foreign exchange market and, if persistent, it has an adverse effect on the volume of international trade as well (Bini Smaghi (1991)).

This paper investigated the objectives of daily foreign exchange market intervention by the Deutsche Bundesbank and the Federal Reserve System in the U.S. dollar-Deutsche Mark market. No information was available about the (degree of) sterilization of the money market effect of the interventions. According to Humpage (1991, p. 13), "none of the G-3 countries completely divorces its intervention activities from its domestic monetary policies; these countries either occasionally adopt exchange-rate targets for their monetary policies, or they do not always completely sterilize their intervention". Convincing empirical evidence of a significant effect of central bank intervention, be it sterilized or unsterilized, on the exchange rate is still lacking (for detailed surveys of empirical investigations into the effectiveness of intervention see Almekinders and Eijffinger (1991), Humpage (1991), Edison (1992) and Belongia (1992)).

Appendix

In Tobit analysis, the likelihood of each subsample has a component for the observations that are positive (or negative, depending on whether the central banks bought or sold U.S. dollars) and a component for the observations that are zero.

For the observations with $INV_t = 0$ it is known that

$$d_0 + d_1\left(S_t^P - \frac{1}{21}\sum_{n=1}^{7} S_{t-n}^{P/F/U}\right) + d_2 h_t + \mu_t^* \leq 0 ,$$

so

$$Pr[INV_t = 0] = Pr\left[\mu_t^* \leq -d_0 - d_1\left(S_t^P - \frac{1}{21}\sum_{n=1}^{7} S_{t-n}^{P/F/U}\right) - d_2 h_t\right]$$

$$= Pr\left[\frac{\mu_t^*}{\sigma} \leq \frac{\left(-d_0 - d_1\left(S_t^P - \frac{1}{21}\sum_{n=1}^{7} S_{t-n}^{P/F/U}\right) - d_2 h_t\right)}{\sigma}\right]$$

$$= 1 - F_t$$

where Pr denotes the expected probability and F_t is the standard normal cumulative density function evaluated at

$$\frac{\left(d_0 + d_1\left(S_t^P - \frac{1}{21}\sum_{n=1}^{7} S_{t-n}^{P/F/U}\right) + d_2 h_t\right)}{\sigma}$$

For the T observations for which INV_t is nonzero an ordinary probability density function applies. The log-likelihood function is given by

$$L = \Sigma_0 \ln(1 - F_t) - \left(\frac{T}{2}\right)\ln 2\pi - \left(\frac{T}{2}\right)\ln\sigma^2$$

$$- \Sigma_1\left[\frac{\left(INV_t - d_0 - d_1\left(S_t^P - \frac{1}{21}\sum_{n=1}^{7} S_{t-n}^{P/F/U}\right) - d_2 h_t\right)}{2\sigma^2}\right]$$

where Σ_0 and Σ_1 denote the sum over the zero observations and the sum over the positive (first subsample for both central banks) or negative (other subsamples) observations, respectively. Amemiya (1973) proves that, if the log-likelihood is maximized, the ML estimators for this model are consistent and asymptotically normal.

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